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SEVERE/TORNADIC THUNDERSTORM DEVELOPMENT AND
EVOLUTION BASED ON SATELLITE AND
AVE/SESAME/VAS DATA Final Technical Report
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INVESTIGATIONS OF SEVERE/TORNADIC THUNDERSTORM DEVELOPMENT
AND EVOLUTION BASED ON SATELLITE AND AVE/SESAME/VAS DATA

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I. Introduction

In September 1983, the Cooperative Institute for Research in the Atmosphere (CIRA) received first year funding for a proposed three year effort "Investigations of Severe/Tornadoic Thunderstorm Development and Evolution Based on Satellite and AVE/SESAME/VAS data." The grant, which was administered during the first out of the NASA Mesoscale Processes Research Program, is in the process of being revised so that its final two year will be administered as a contract from NASA's Marshall Space Flight Center (MSFC). This report is issued as a final technical report for the first year's efforts and includes a final section on future work areas to be investigated with MSFC.

Under this grant, scientific investigations were undertaken in three areas. Those areas were: 1) uses of research rapid scan satellite imagery to investigate the severe thunderstorm's local environment; 2) investigations of the April 10, 1979 AVE/SESAME case using rapid scan satellite imagery and AVE sounding data; and 3) investigations of VAS imagery for mesoscale applications. Each of the three above areas were investigated with the premise that they were part of a three year or longer collaborative effort. The major emphasis has been in area #1. Several other activities have been undertaken in conjunction with this grant, although all were not totally funded by it. They include: 1) providing briefing materials to Dr. James C. Dodge, Manager, NASA Mesoscale Processes Research Program; 2) participation in two NASA program reviews; and 3) a number of presentations and papers. These are briefly discussed in the sections that follow.

II. Using satellite research rapid scan imagery to investigate the severe thunderstorm environment - vertical wind shear and storm relative flow

a. An important new technique for mesoscale cloud tracking

Because of the tremendous number of observations that can be obtained with satellite data in mesoscale space and time domains, satellite cloud motion fields have great potential for studying the precursor severe storm environment and other mesoscale phenomena. While the potential of mesoscale cloud tracking has been demonstrated, considerable difficulty may be encountered when attempting to create mesoscale flow fields using rapid scan satellite imagery. This is especially true the more strongly sheared the environment in which the clouds to be tracked are developing.

In a highly sheared severe storm environment with strong low level flow, cumulus clouds move rapidly as they evolve over short time periods. Under such conditions, the top portion of a cumulus may be vertically growing while also moving in a direction that is different from its lower portion. The rapid movement and growth of the cumulus in a sheared environment can produce a confusing picture to the cloud trackers and make the determination of accurate cloud motions very difficult. With these thoughts in mind, a new and simple method for mesoscale cloud tracking was developed for the CSU IRIS system.

In the new method, a cloud whose motion is representative of the cloud field of interest is identified. That cloud is then tracked, and its motion is used to re-navigate the original sequence of images over the area of interest. When this re-registered image sequence is viewed in animation, the "representative cloud" is stationary as are other clouds like it. With the mean motion having been extracted from the cloud field, variations in motion between similar clouds as well as growth, decay and shear are readily detectable.

While the tracking of clouds in a cloud relative mode may seem the same in principal to that in an earth relative framework, it is not. There is a very basic and fundamental difference. For now instead of following a cloud from one point to another, the function of the cloud tracker has changed. The analyst is now monitoring cloud growth and asynchronous translation over a finite amount of time and assigning displacements to appropriate portions of that cloud - this is easy to do since the cloud is basically standing still and we are observing its evolution. This same function is extremely difficult to do in earth relative coordinates where a cloud is seen to rapidly translate as it changes character.

b. Vertical wind shear and thunderstorm relative flow

It is well known that vertical wind shear plays an important role in determining the character of storms that evolve in a mesoscale environment. Furthermore, recent numerical cloud modeling studies have shown the importance of vertical wind shear in the formation of rotation in growing thunderstorms. However, a severe storm environment is one in which both the dynamic and thermodynamic characteristics of the atmosphere are changing on mesoscale space and time domains. Using our new method noted above, determination of vertical wind shear in regions of growing cumulus clouds using rapid scan satellite imagery is now feasible. We can study mesoscale variations in that parameter over large areas.

After thunderstorms have developed, animation of the imagery may be done relative to the thunderstorm. In such cases, the flows at different levels with respect to the storm may be inspected. Such a study was undertaken for the storm which produced the Wichita Falls tornado on April 10, 1979. A GOES-East view of that storm at 6:15 PM CST is shown in the attached papers along with the relative flow derived from 3 minute interval GOES-East data at low, middle and high levels with respect to the Wichita Falls storm. Figure 25 from the

"Convective Scale Weather Analysis and Forecasting" chapter draft shows the storm relative flow for the 28 March 1984 super cell storm discussed in that chapter. It is interesting to note how closely those relative flows compare to those for severe storms which travel to the right of the wind, and storm relative proximity soundings. Being able to diagnose storm relative flow has important implications for defining mesoscale regions that are favorable for the production of rotating storms and severe weather.

III. Investigations of the 10 April 1979 tornado outbreak - The role of pre-existing low level cloud cover in the warm sector

Earlier work using satellite imagery has shown the strong effect early morning cloud cover may have on afternoon thunderstorm development. Our work on the April 10, 1979 tornado outbreak shows that early cloud cover can also influence the development of intense convection under conditions of strong synoptic scale forcing. On April 10, a mesoscale frontal boundary helped focus tornado activity in the Red River Valley area of Texas and Oklahoma. The most probable cause of that meso-front was differential heating due to cloud cover to its east versus a clear area to its west. The mechanism which led to the development of the meso-front, and subsequent focusing of tornadic activity, also played an important role in the development of instability in the warm sector. As the mesoscale frontal boundary moved eastward, mostly clear skies developed in the warm sector between the boundary and the stratiform overcast to its east. During that period Abilene, Texas became clear while Stephenville, Texas maintained its cloud cover. An analysis of surface static energy pointed to strong potential instability at both Abilene and Stephenville. However, time series of horizontal cross sections from mesoscale rawinsonde data from NASA's AVE SESAME experiment show a marked decrease in the amount of negative buoyant energy at Abilene and only a slight decrease at Stephenville; these changes are

related to changes in cloud cover. Low level air, similar in character to that near Abilene fed the tornadic storm system, allowing intense thunderstorms to develop.

Thus we see that the effect of early morning cloud cover can be complicated indeed. It can act to set up a baroclinic zone (or reinforce an existing one) through differential heating. At the same time, it can effect the local destabilization of an airmass: a) if skies clear too quickly, moisture may be mixed to great depths making the region unsuitable for supporting strong moist convection; b) if the area remains cloudy, thunderstorms moving into the region might dissipate or weaken considerably due to the negatively buoyant low level air; c) if the area clears an hour or two prior to thunderstorms moving into it, sufficient heating and mixing at low levels may have occurred, priming the local air mass to support explosive convection. Use of VAS sounding channel data should aid in the assessment of the convective potential of such situations for mesoscale forecasting.

IV. VAS imagery for mesoscale applications

Work is currently underway which combines various channels of VAS data in image format to try and detect the development mesoscale structure in the atmosphere. In that work features such as vorticity maxima, jet streaks, thunderstorm complexes, etc. are being studied in time lapse in a "system" relative mode similar to that discussed previously. Results look very promising for detecting developing baroclinic regions as well as isolating mesoscale regions of stronger vertical forcing.

The 6.7 μm channel data depicts regions of middle level moisture and clouds. Distinct patterns of more moist and cooler areas and warmer and drier areas are readily detected. These features are related to areas of both

synoptic and mesoscale advection and vertical motion. When viewed in time lapse, they exhibit excellent spatial and temporal continuity. Strong baroclinic regions such as jet streams and vorticity maxima can often be easily identified in cloud free regions by the sharp moisture gradient detected in the 6.7 μm image.

There are clues in the 6.7 μm data concerning a storm's ability to produce severe weather. During the March 28, 1984 tornado outbreak there was a significant mid-level dry region on the southern side of the tornadic storm complex. Mid-level storm relative flow for this case is from the SSE. This points to the likelihood of significant mid-level dry intrusion into the storm system. Such an intrusion of dry air could help fuel the storm's downdraft (outflow) and increase the possibility of that storm producing tornado activity - a sort of forced dynamic/thermodynamic instability.

V. Publications - totally or partially supported by this grant

a. Preprints - copies are attached

1. Purdom, J.F.W., T.H. Vonder Haar, J.K. Stewart and N.E. Leary, 1984: Diagnosing the severe thunderstorm environment by mesoscale cloud tracking - a new approach and new information. Conference on Satellite/Remote Sensing and Applications, Clearwater Beach, FL, Amer. Meteor. Soc., 100-105.

2. Purdom, J.F.W., 1984: Use of satellite soundings and imagery for nowcasting and very-short-range forecasting. Preprints, Nowcasting II Symposium, Norrköping, Sweden, European Space Agency, 99-111.

b. In Progress

1. Purdom, J.F.W. "Convective Scale Weather Analysis and Forecasting," Chapter for 25th Silver Anniversary Book on Meteorological Satellites - draft attached.

2. Segal, M., J.F.W. Purdom, R.A. Pielke and Y. Mahrer. "Evaluation of Stratiform Cloud Shading Effects on the Generation and Modification of Mesoscale Circulations."

c. Summary Abstracts

1. Purdom, J.F.W. and T.H. Vonder Haar, 1984: Investigations of severe/tornadic thunderstorm development and evolution based on satellite data. Mesoscale Atmospheric Processes Research Program Science Review, NASA, GSFC, April 25-26.

VI. Presentations - Portions of the presentations listed below used information from this grant.

1. Purdom, J.F.W., 1984: Satellite data and mesoscale applications. U.K. Meteorological Office, Bracknell, U.K.

2. Purdom, J.F.W., 1984: Diagnosing the mesoscale state of the atmosphere. KNMI, De Bilt, Netherlands.

3. Purdom, J.F.W., 1984: Uses of satellite soundings and imagery for nowcasting and very-short-range forecasting. Nowcasting II, Norrkoping, Sweden. Invited presentation.

4. Purdom, J.F.W., 1984: What we've been doing with KRCD and VAS. Wallops Island, CDA station.

5. Purdom, J.F.W., 1984: Satellite data for nowcasting. NESDIS, Suitland, MD.

6. Purdom, J.F.W., 1984: How satellite imagery can help us to understand the small scale atmosphere. Annual General Meeting of the Royal Meteorological Society Australian Branch, Sydney, Australia.

7. Purdom, J.F.W., 1984: Satellite clues to the development of severe thunderstorms. Bureau of Meteorology, New South Wales Regional Office, Sydney, Australia.

8. Purdom, J.F.W., 1984: Investigations of severe/tornadic thunderstorm development and evolution based on satellite data. Mesoscale Atmospheric Processes Research Program Science Review.

9. Purdom, J.F.W. Diagnosing the severe thunderstorm environment by mesoscale cloud tracking - a new approach and new information. Conference on Satellite Meteorology/Remote Sensing and Applications, Clearwater Beach, FL.

VII. NASA Program Reviews

1. Mesoscale Atmospheric Processes Research Program Science Review, NASA/GSFC, April 25-26, 1984.

2. FY-84 Atmospheric Processes Research Program Review Involving Mesoscale Processes Research, NASA/MSFC, May 2-3, 1984.

VIII. Future Plans

Work under NASA Grant NAGW-504, "Investigations of severe/tornadic thunderstorm development and evolution based on satellite and AVE/SESAME/VAS data" is off to a great start. We expect to continue in such a highly productive mode as the grant becomes a contract administered out of Marshall Space Flight Center.

Emphasis will continue in exploitation of system and storm relative modes for inspecting meteorological satellite data, especially cloud relative flow, asynchronous translations (related to shear) and cloud growth. We feel this holds great promise in leading to a better understanding of situations in which tornadic storms feed off of their own outflow versus those situations in which they feed off of the outflow from another storm in their near environment. Especially important in this portion of our work will be the inclusion of 6.7 μ water vapor information. Our work using AVE data sets, with emphasis on days when either rapid scan satellite imagery and/or VAS multispectral imagery are available, will continue with an emphasis toward relating storm severity to environmental evolution. This would include a large number of cases with a wide range of severe weather including high winds, heavy rains, and general thunderstorm activity.